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INVENTORY MANAGEMENT OF REPAIRABLES IN THE U.S. MARINE CORPS - A VIRTUAL WAREHOUSE CONCEPT

by

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June 2000

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ABSTRACT

The 1998 Department of Defense (DoD) Logistics Strategic Plan directed a sweeping program to reform the "business" of the DoD. A key component of the plan is that inventories be established at the lowest possible levels and be positioned to permit rapid delivery to the customer. In response, the Marine Corps has established a "virtual float" concept that seeks to reduce inventory levels for secondary repairables (SecReps). We show through a simulation model that the Marine Corps should not expect large savings from a virtual float operating with a lateral transfer inventory policy. For the items we selected, additional transportation costs for lateral transfers almost entirely eliminated savings due to reduced inventory. We also address organizational issues involved with a centralized system.

TABLE OF CONTENTS

I. INTRODUCTION 1

A. BACKGROUND 1

B. PURPOSE 4

C. METHODOLOGY 5

II. THE CURRENT SUPPLY CHAIN FOR SECONDARY REPAIRABLES 9

A. REPAIRABLE ISSUE POINT FUNCTION 9

1. Categories of Customers and SecReps 11

2. Demand Based Sparing 13

B. RELATED RESEARCH 15

III. SECREP SUPPLY CHAIN SIMULATION 19

A. MODELS 19

1. Inventory Logic 22

2. Repair Process Logic 26

B. MODELING DEMAND 29

C. WEAKNESS OF MODEL 30

D. RESULTS 31

E. OTHER ISSUES 36

IV. CONCLUSIONS AND RECOMMENDATIONS 41

A. CONCLUSIONS 42

B. RECOMMENDATIONS 43

C. FUTURE 44

APPENDIX A. SUPPLY AND MAINTENANCE EFFORT 47

APPENDIX B. SERVICE STANDARDS FOR OVERNIGHT TRANSPORTATION 49

LIST OF REFERENCES 51

BIBLIOGRAPHY 53

INITIAL DISTRIBUTION LIST 55

I. INTRODUCTION

A. BACKGROUND

> *We must always be ready, so that if an enemy approaches us with a sharp sword, we do not meet him only armed with an ornamental rapier.*
>
> Carl von Clausewitz

General Carl von Clausewitz offers a lesson that many military forces have used as a basis for establishing inventories for war. Today, large inventories represent inefficiencies and opportunity forgone. The 1998 Department of Defense (DoD) Logistics Strategic Plan directed a sweeping program to reform the "business" of the DoD. In response, the Department of the Navy's Business Vision and Goals statement asserts that, as the Cold War ended, the U.S. private sector revolutionized business practices in response to increasing foreign competition and a rapidly expanding global economy [Ref. 1].

> *Over the past decade, the American commercial sector has reorganized, restructured, and adopted revolutionary new business practices in order to ensure its competitive edge in the rapidly changing global marketplace. It has worked. Now the Department must adopt and adapt the lessons of the private sector if our Armed Forces are to maintain their competitive edge in the rapidly changing global arena.*
>
> *The Department has made much progress already . . .. However, we need to go much further and deeper, and we need congressional support.*
>
> Secretary of Defense William S. Cohen
> The Report of the Quadrennial Defense Review

One of the fundamental principles described within the DoD Logistics Strategic Plan [Ref. 2] is that inventories be established at the lowest levels possible, and that they be positioned to permit rapid delivery to the customer. Among the objectives of the DoD

Logistics Strategic Plan are the reduction of worldwide inventories to achieve the DoD and National Performance Review (NPR) goals and the implementation of a "virtual" inventory control point structure within each component. A "virtual" inventory control point, as defined within the plan, is a management structure for multiple, geographically separate inventory control points under a single command. There is a common overhead support structure (e.g., personnel, finance, automated data processing (ADP) systems) that integrates the operation of multiple sites through electronic communication interfaces. [Ref. 1]

In order to bring modern business practices into Marine Corps logistics, the Marine Corps has established a "virtual float" concept, which seeks to reduce inventory levels for secondary repairables (SecReps). SecReps are items designated as repairable, where repair is more economical and timely than purchase. Additionally, SecReps provide each Marine Expeditionary Force (MEF) commander with a pool of critical items to facilitate high levels of equipment readiness. This ensures that the principal end items (PEI) can be brought out of combat deadline status by a pool of critical SecReps. [Ref. 3]

Currently, each MEF has a combat service support (CSS) organization to support its ground operations. Operating in four geographical regions, each CSS organization independently owns and manages an inventory of SecReps. The Supply Management Business Area (SMBA) of the Navy Working Capital Fund (NWCF) dictates the methodology for buying and selling repairable assets. Each CSS organization computes its individual requirements and then establishes requisitioning objectives (RO) and

allowances accordingly. The total allowance incorporates the computed RO plus local considerations to accommodate contingency requirements and potential data inaccuracy (safety stock). The result has been excessive stocks throughout the Marine Corps. Because each CSS organization determines the number of repairables to maintain through an item approach, which is to buy enough repairables to cover the lead-time demand plus some safety level to protect against demand variability, more SecReps are maintained within the Marine Corps Supply system than required. [Ref. 3]

The inventory policy for SecReps within the Marine Corps can be further characterized as a decentralized stock of repairables maintained through active and reserve establishments. The Support activity supply system (SASSY) Management Units (SMU) operate within each CSS organization to manage and control SecReps in a region, including all elements of the supported MEF. Funding is allocated to each MEF through the local SMU, based upon the factors that make up a stock computation formula and the historical local experience with washout rates. In response to maintenance requests from using units or customers of the SMU, SecReps are obtained from either a source of supply (SOS) in the case of a washout, off the shelf of the maintenance float activity as a direct exchange, or a delayed issue in the case of maintenance backlog or backorder (BO) situation. In the case of a request submitted from a geographically dislocated unit, the item is passed to a DoD transportation management office (TMO) for shipment using either Defense Transportation System or commercial assets. The SecRep is then received

at the supporting TMO and distributed to the requesting unit. The present dollar value of SecReps stocks in the Marine Corps is listed in Table 1.1.

Location	Inventory Value
Marine Corps Logistics Bases	$391,000,000
East Coast active forces	$162,645,000
West Coast active forces	$135,230,000
Okinawa active forces	$82,118,000
Blount Island Command	$40,661,000
Reserve Forces	$32,262,000
Hawaii active forces	$16,950,000
Total	**$860,866,000**

Table 1.1 Current Inventory Values of SecReps by Location [Ref. 3]

B. PURPOSE

The purpose of this research is to examine inventory management of repairables within the U.S. Marine Corps and to evaluate the potential benefits involved with establishing a virtual warehouse to manage SecReps. The VW will set the framework for centralized management of all SecReps and provide the foundation for applications used for future inventory management. Using a simulation model, we consider trade-offs associated with centralized inventory management, stock reduction, and transportation costs. Specifically, we address the following questions: Given consolidated management of secondary repairable items through a "virtual warehouse concept", what overall inventory policy satisfies demand while minimizing inventory holding cost and transportation cost? Moreover, what are the potential issues and problems involved with centralized management?

C. METHODOLOGY

We present two simulation models for management of SecReps within a virtual warehouse. First, we model an inventory management policy that does *not* allow lateral re-supply between bases. The model describes the demand placed on the supply system at the using unit level (MEF supported units) and the subsequent demand placed on the Marine Corps Depots. Figure 1 illustrates the flow of material without lateral re-supply.

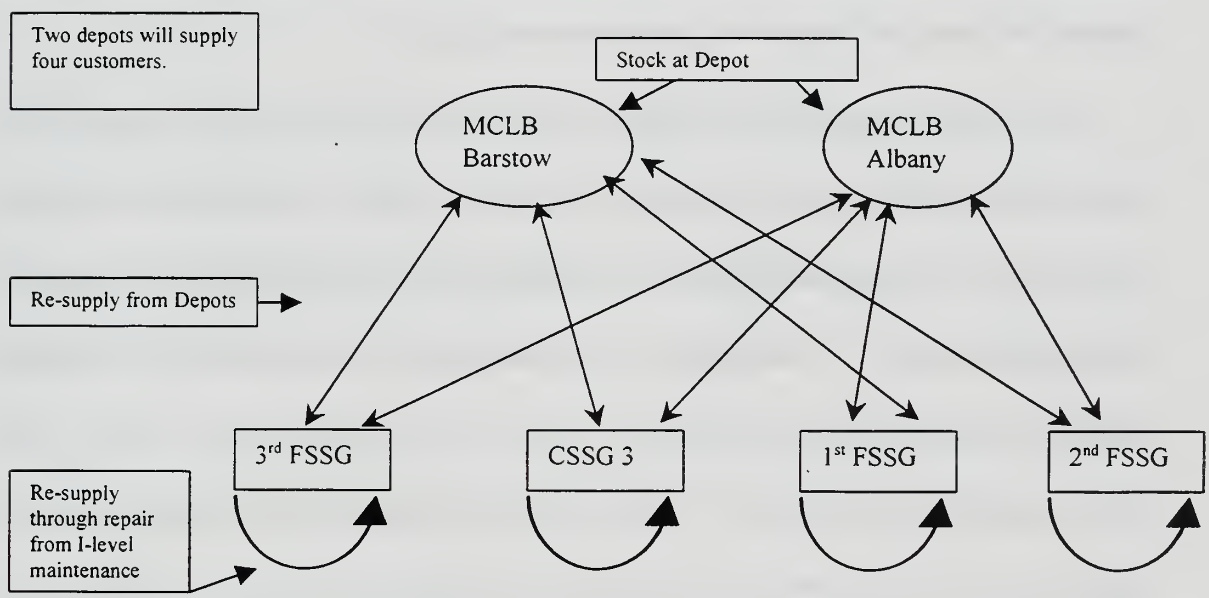

Figure 1. Flow of Material Without Lateral Re-supply

The second model describes an inventory management policy that *does* allow lateral re-supply between bases. The model also describes the demand placed on the supply system at the using unit level (MEF supported units) and the subsequent flow of demand placed on the Marine Corps Depots.

Demand for the SecReps we selected was based on the mean time between failure (MTBF) of the items. As the SecRep fails, it generates a demand for a replacement SecRep. We obtained estimated demand and MTBF data from interviews with intermediate level and depot-level maintenance personnel. We obtained transportation cost data from a representative LTL carrier. Costs are based on the rate provided to the government for transportation to and from each node in the supply network. Our conceptual model of the Marine Corps repair process is based on interviews with intermediate level and depot-level maintenance personnel.

Our results suggest that the Marine Corps should not expect large savings from a virtual float operating with a lateral transfer inventory policy. For the items we consider, we show that additional transportation costs significantly offset holding cost savings for a lateral transfer policy. Additionally, our research also reveals that there are significant issues that should be determined before moving to a centralized inventory system: How will a virtual float be structured? Will all the participants within the supply chain have equal input? Does the central item mangers have adequate information to make informed decisions about how much to stock and where to stock required SecReps? Is there enough capacity and resources at each node in the supply chain to support lateral transfers of SecReps? If there are two or more locations with the same requirement at the same time, who within a virtual float will decide which location will receive the support?

The rest of the thesis is organized as follows: Chapter II describes the current supply chain for SecRep items, how inventory levels are currently set throughout the

Marine Corps, and related research in repairable inventory management. Chapter III addresses our research questions through a SecRep inventory simulation model and presents issues concerning centralized management of inventories. We describe the data used to support our research and the results of the simulations. Chapter IV presents conclusions and recommendations.

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II. THE CURRENT SUPPLY CHAIN FOR SECONDARY REPAIRABLES

We present an overview of the basic functions of the repairable issue point (RIP) and the current supply chain for secondary repairable items. Additionally, we describe the demand based sparing (DBS) methodology currently used to determine inventory levels for SecReps and discuss relevant studies in repairable inventory management.

A. REPAIRABLE ISSUE POINTS

Repairable issue points provide a pool of repairable assets available for direct exchange by using units. The RIP also serves as the intermediary between using units and supporting repair facilities. RIPs are located within the Fleet Marine Force (FMF) and are managed by the Force Service Support Group (FSSG) for common-ground assets and individual units for Critical Low Density (CDL) assets. The primary functions of a RIP include:

- Computing RIP allowances to determine how many SecReps to hold.
- Producing a catalog of items held to provide to their customers and requisition SecReps as needed.
- Receiving and distributing SecRep assets.
- Returning RIP items to the Depot Maintenance Activities (DMAs) or to commercial vendors.

- When directed, budgeting and managing funds required for RIP asset replenishment, including customer charges for assets issued store account code one (SAC 1) without an unserviceable turn-in.

Additionally, each RIP conducts and arranges the RIP inventory by identifying assets for redistribution and ensuring that on hands are within authorized allowances. RIPs also control and monitor repair cycle times (RCT) for assets being repaired and establish repair priorities of assets to maximize support for their respective customers [Ref. 5].

Current Marine Corps policy [Ref. 5] states that repair will be accomplished at the lowest possible echelon of maintenance. When unserviceable items require repair, secondary repairable items are made available on a direct exchange basis. When an unserviceable SecRep cannot be repaired locally, using units exchange the item at the appropriate RIP. If the RIP does not have a serviceable SecRep on the shelf, a back order is established upon turn-in of the unserviceable SecRep. Appendix A, which is based on a 1996 study of repair cycle times (RCT) and order ship times (OST) conducted by the Field Supply and Maintenance Analysis Office-3 (FSMAO-3) [Ref. 6], describes the supply and maintenance effort in detail and the functions that the RIP has within the overall maintenance process. Figure 2 illustrates the process.

To ensure uniform management of repairable items throughout the Marine Corps, management is based upon the Source Maintenance and Recoverability Code (SMRC) assigned to each item entering the Marine Corps inventory during the initial issue provisioning process. A SMRC is a five-digit code that identifies the echelons of

maintenance required to condemn, repair, or remove an item from service. The code is broken into three parts: source code, maintenance code, and recoverability codes. [Ref. 7]

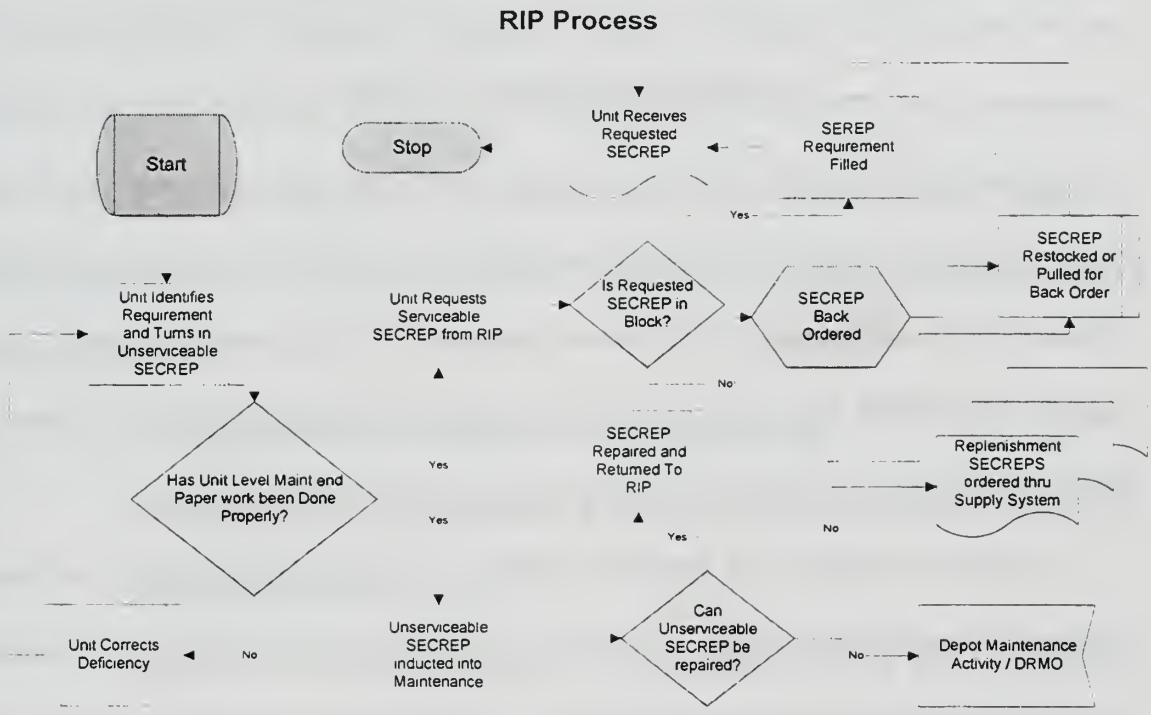

Figure 2. RIP Process

The source code, which makes up the first and second digits, is assigned to an item to indicate the manner of acquiring the support item for maintenance repair, or overhaul of an end item. Although the code is primarily used at the wholesale level, the RIP is generally concerned with the code because it identifies how the repairable is assembled, procured or stocked. For example, in the SMRC **PAFHH**, **PA** indicates that the item is to be procured and stocked for anticipated, known usage. This indicates that

the equivalent to a RO/ROP would be established for this item at the wholesale level. [Ref. 7]

The maintenance code identifies the echelon of maintenance authorized to remove, replace, and completely repair a secondary repairable. The first digit of the maintenance code, which is the third position of the SMRC, indicates the lowest echelon of maintenance authorized to remove or replace a secondary repairable item. The second digit of the maintenance code or fourth position of the SMRC is the repair code, which indicates the lowest echelon of maintenance authorized to affect complete repair. In our example of **PAFHH**, **FH** indicates that a 3rd echelon maintenance shop can remove an item and a 4^{th} echelon maintenance shop can repair an item. [Ref. 7]

The recoverability code identifies whether or not an item is repairable, and more importantly, the disposition action to be taken for an unserviceable asset. In our example of PAFHH, **H** indicates that the item should be condemned and disposed of at 4^{th} echelon maintenance.

1. Categories of Customers and SecReps

Repairable issue point customers fall into two categories: using units, such as battalions, aircraft groups, and companies; and maintenance shops of the Intermediate Maintenance Activities (IMAs) [Ref. 5]. Table 2.1 indicates the number of customers supported and the number of SecReps managed through each RIP [Ref. 8].

MEF	Supporting SMU	Number of customers Supported	Number of items Managed
I MEF	1st FSSG	118	2500
II MEF	2nd FSSG	125	3100
III MEF	3rd FSSG	76	2300
	CSSG 3	13	1800

Table 2.1 Number of Customers

There are six possible situations in which RIP customers may warrant an exchange between the RIP and supported customers and cause a decrease in RIP inventory [Ref. 9].

- A customer turns in a SecRep and is issued a like item.
- A customer turns in a SecRep and is issued a SecRep that is different from the item being turned in.
- A customer turns in a SecRep in which the RIP does not have the item on-hand (OH) and must BO the required SecRep.
- A customer has a requirement for a SecRep, but does not have a carcass to turn in for repair. The RIP issues the item without a carcass turn-in.
- A customer has a requirement for a SecRep, but does not have a carcass to turn-in for repair and the RIP does not have the item to issue. The RIP BOs the item without a carcass turned-in.
- A BO that was previously cancelled is reinstated to fill a customers requirement.

Secondary repairable items are separated into two distinct categories: Depot Level

Repairable (DLR) and Field Level Repairable (FLR). DLR items are items that can be repaired, which repair is the primary source of supply for the item. Before a new DLR item is ordered, every attempt is made to repair the item. Customers waiting for DLR items are normally waiting on the repair cycle time (RCT) for the asset vice the order ship time (OST) of a new DLR item. The Marine Corps determines if a SecRep can be considered a DLR item by the following criteria: if rebuilding or repairing the SecRep lower than a fifth echelon maintenance activity (depot level) adversely diminishes the mobility or dilutes the maintenance support capability of the FMF, because of special skills, tools, or test equipment not maintained within the FMF, the item is considered a DLR and is repaired only at the depots. When DLR items are required by FMF customers, each RIP provides the required DLR item and ships the carcass DLR to the depot for repair. When the RIP computes inventory levels for DLR items, consideration is given to order ship time from the depot to the RIP. In contrast, FLR items are repaired at the lowest level of maintenance by IMAs and normally do not require special test equipment, tools, or skills not maintained within the FMF. [Ref. 9]

2. Demand Based Sparing (DBS)

Demand based sparing has been a staple method used for inventory management within the Marine Corps. Stock levels are determined independently of decisions to stock other items and are often based on usage data, which indicates how often an item has been requested over a given time horizon. The depth of an item is determined by requisitioning objective (RO) and repair cycle requirement (RCR).

Currently each RIP computes its individual requirement and then establishes an RO. The total allowance incorporates the computed RO plus local considerations to accommodate contingency requirements and safety stock. The RO is calculated based on the following formulas [Ref. 3]:

$$RO = RCR + OSR + SL$$

$$RCR = \frac{(RR * RCT)}{30},$$

where,

RR = Repair Rate

RCT = Repair Cycle Time

RCR = Repair Cycle Requirement

OSR = Order Ship Requirement

SL = Safety Level

RO = Requisitioning Objective

The *requisitioning objective* (RO) specifies the stock level at which a replenishment order is placed. This is similar to the use of *reorder points* (ROP) for consumable items. The *repair cycle requirement* (RCR) considers how long it takes to repair a given SecRep by measuring the *repair rate* (RR) and the *repair cycle time* (RCT) over a thirty (30) day period. The RR is the number of items successfully repaired per month. The RCT is the time between a SecRep being known to be faulty and the time it is repaired and available for issue again. The RO is set to minimize the risk of stock-out between the time a SecRep is issued and the carcass is repaired and ready for subsequent

issues. Each RIP must trade-off between the cost of incurring one or more stock-outs and the cost of holding additional stock to cover the possibility of unanticipated demand. *Safety levels* (SL) are set to protect against demand variability during the lead-time. In the case of SecReps, the repair rate of the local IMA and the order ship requirement, which is the number of items requested from the RIP minus the RR, are factors considered during the lead-time. Because of the decentralized nature of management for SecReps, each RIP computes its RO independent of the depot and other RIPs. As a result, SL stocks are maintained above what the overall system requires. The overall system is the total requirement for the Marine Corps vice the requirement of each MEF [Ref. 3]

Unlike the commercial sector, Marine Corps inventory requirements are driven by national security commitments and training requirements. Since foreign crises frequently flare up with no warning and many critical SecReps have lead times that are significant, the Marine Corps maintains stock for items it may never use as insurance against the threat of a foreign crisis.

B. RELATED RESEARCH

We focus on reducing SecRep inventory levels throughout the Marine Corps by simulating the supply chain and reducing the depth of SecReps maintained at each location (1st FSSG, 2nd FSSG, 3rd FSSG, CSSG-3, MCLB Barstow, and MCLB Albany) to reduce inventory cost and provide the same level of service.

Other studies, such as readiness based sparing (RBS) methodology, currently used by the Navy, Army, and Air Force, are based on the multi-echelon techniques for

recoverable item control (METRIC) developed by Sherbrooke [Ref. 10]. Sherbrooke examined repairable inventory management through a *system approach*, which asks such questions as: How can we insure that 95% of our weapons systems will be not be delayed for lack of spare parts? and, How much more money do we need to move from 95% to something higher? More generally, Sherbrooke discusses what can we do to change our logistics support structure to achieve a desired availability more efficiently? Is it economical to have more repair capability at the operating sites? Sherbrooke contends that a system approach is superior to an item approach because it provides management with predictions of availability levels with reduced inventory investment.

Readiness based sparing is a *system approach* based on the premises set forth by Sherbrooke whose goal is to maximize the operational availability of a weapon system within management imposed budgetary constraints. Operational availability (A_o) is the percentage of time that a system is capable of performing its intended function. Figure 3 illustrates the components of operational availability. Key to operational availability is the elements contained in "downtime". Figure 4 From [Ref. 11] illustrates the components of downtime.

TIGER is the U.S. Navy approved reliability, maintainability and availability (RMA) simulation model, which is a time-continuous reconstruction of a weapons systems' "average" mission involving simultaneous consideration of the system and other events [Ref. 12]. NAVSEA uses a simulation model instead of deterministic equations because: as a system's complexity increases, so do the number of variables necessary to define the system and the number of associated equations to be solved through

deterministic methods. NAVSEA contends that when one adds in repair, re-supply, partial degradation, variable duty factors, variable operating factors, allowed downtime events, and all the other variable complexities of real-life system operations, the more difficult it becomes to write probability of success formulae's required by deterministic methods. NAVSEA asserts that a simulation can handle these complexities. [Ref. 11]

Within the private sector, similar arguments have been made with respect to use of simulation modeling. Archibald, et al. [Ref. 13: p.4] utilize the IBM Supply Chain Analyzer, a supply chain simulation model, to demonstrate the financial impact of several supply chain policy alternatives. The authors indicate that as companies rely on a mix of suppliers, transportation resources, assemblers, warehousing firms, and retail outlets to bring their product to the market, it becomes difficult to determine the impact of changes in performance with any of the elements in the supply chain. Archibald, et al. conclude that using a simulation model as a tool to give visibility of the entire supply chain can allow for the testing of numerous "*what if*" scenarios such as outsourcing, consolidating vendors, collaborative planning, or implementing e-business. The net result asserted by the authors is that companies can achieve significant improvement in operational and financial performance of the entire supply chain by simulating their process and testing proposed policy changes before implementation.

The Marine Corps has started to progress towards RBS by sponsoring studies by the Center for Naval Analyses (CNA), including a review of RBS requirements and the situation of the present state of logistics systems and data collection [Ref. 14]. CNA's [Ref.14, 15] conclusions suggest a difficult road in implementing RBS within the Marine

Corps due to inaccurate data collection. Penrose [Ref. 16] confirms the findings from CNA.

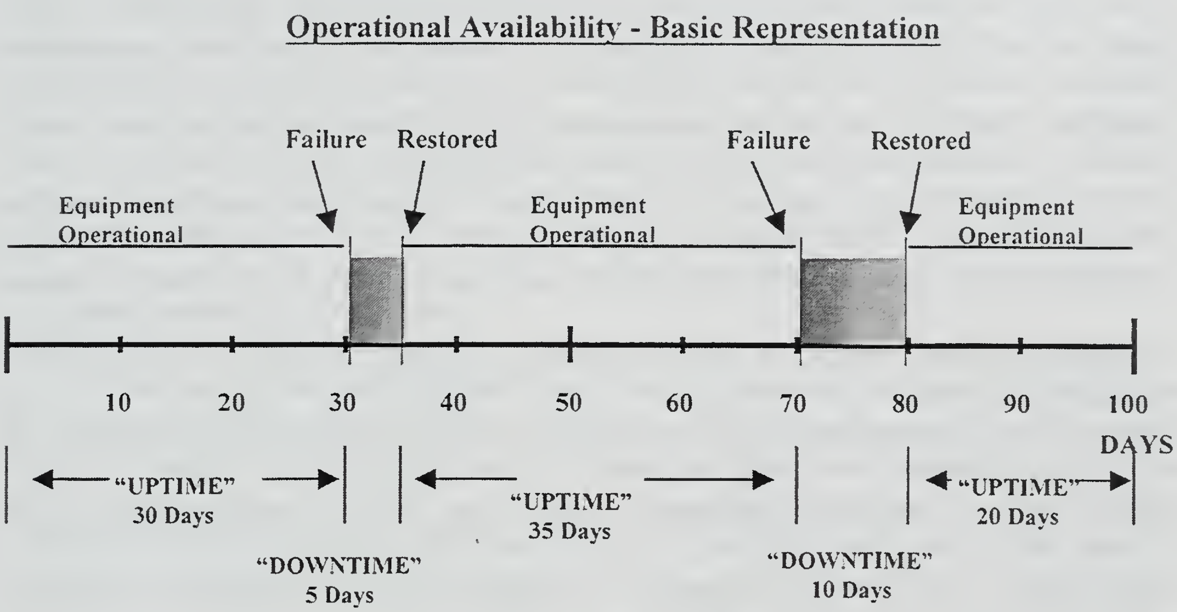

Figure 3. Components of Operational Availability From [Ref. 11].

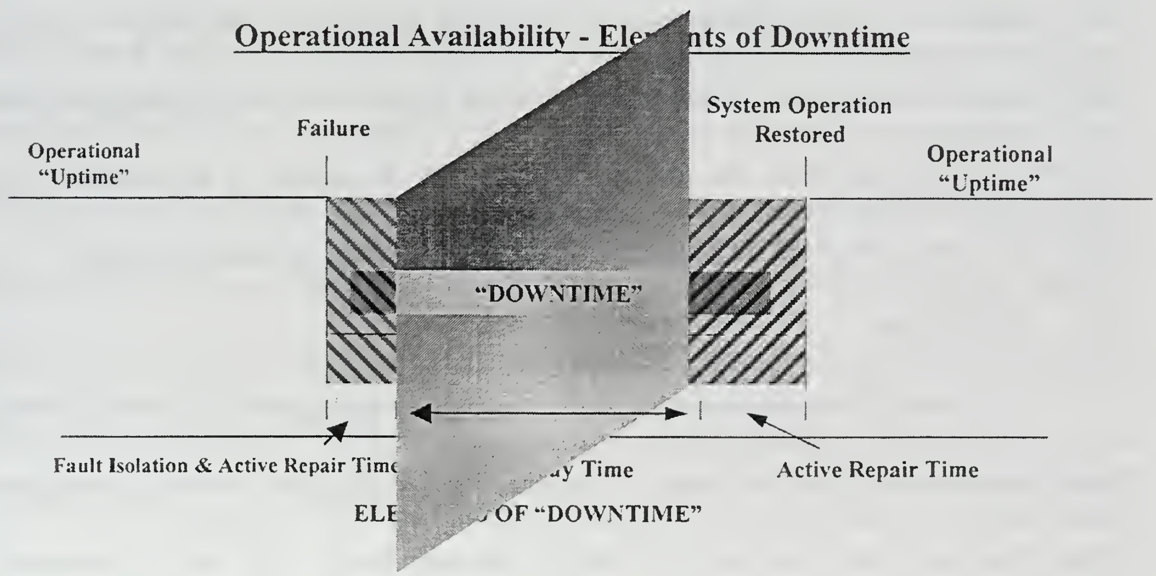

Figure 4. Operational Availability-Elements of Downtime From [Ref. 11].

III. SECONDARY REPAIRABLE SUPPLY CHAIN SIMULATION

Senge [Ref. 35] suggests that in order to determine organizational disabilities, it helps to start with a laboratory experiment...a microcosm of how real organizations function, where you can see the consequences of your decisions play out more clearly than is possible in real organizations. Hicks [Ref. 17] asserts that traditional modeling paradigms do not possess sufficient flexibility and scalability to render effective business solutions, and that simulation and optimization modeling techniques are an effective means to make operational, tactical, or strategic decisions. Ingalls and Kasales [Ref. 18] describe today's business environment as dynamic and driven by many decisions in the supply chain. They state that companies will buffer inventory or carry excess capacity in order to handle the dynamics of the business world.

The purpose of this chapter is to present our SecRep simulation inventory model and to examine inventory management of repairable items within the Marine Corps. We first present an overview of the model and describe the inventory logic, repair process and how we modeled demand. In addition, we provide the results of the simulations and discuss the issues involved with centralized and decentralized inventory systems.

A. MODELS

We present two simulation models for inventory management of SecReps within a virtual warehouse. First, we develop a simulation model of an inventory management policy that does not allow lateral re-supply between bases. The model describes the demand placed on the supply system at the unit level (MEF supported units) and the

subsequent demand placed on the Marine Corps Depots. The SecRep simulation model determines the level of supply required to maintain 90% availability of the PEI at each base. Additionally, the model determines the number of times each base had to be re-supplied from each depot or through inventories held within each base, and the number of times each base could be re-supplied through repair from its IMA. Figure 1.1 illustrates the flow of demand with an inventory policy that is re-supplied through the depots with no lateral re-supply from the bases.

The second simulation model describes an inventory management policy that allows lateral re-supply between bases. Again, the goal is to determine the level of supply required to maintain a 90% availability of the PEI at each base, while allowing lateral re-supply between bases. Lateral re-supply is made whenever a demand at a base causes a backorder (i.e., stock on hand is zero and a customer has a unfilled demand) and a SecRep at some other base can be transported to the base before an item already in transit from a depot or one completing base repair. The model determines the number of times each base had to be re-supplied from each depot or through inventories held within each base, and the number of times each base was able to be re-supplied through repair from its IMA. For example, if a demand for an item is received at 1st FSSG and both depots are out of stock, the model considers the level of inventory at all other bases and selects the required item based on transportation costs and the presence of stock at the base. In our example, 1st FSSG would first search 2nd FSSG because it has the lowest transportation cost, then CSSG-3 because it has the next lowest transportation cost, and complete the search with 3rd FSSG, which has the highest transportation cost. Once the

required item has been located at any of the other bases, the item is sent to 1st FSSG and the search stops. Figure 5 illustrates the flow of material with lateral re-supply. A weakness of the algorithm is that it does not consider forthcoming availability of items in repair. As we will show, this is a significant weakness because transportation costs for lateral transfers are substantial when compared to inventory savings.

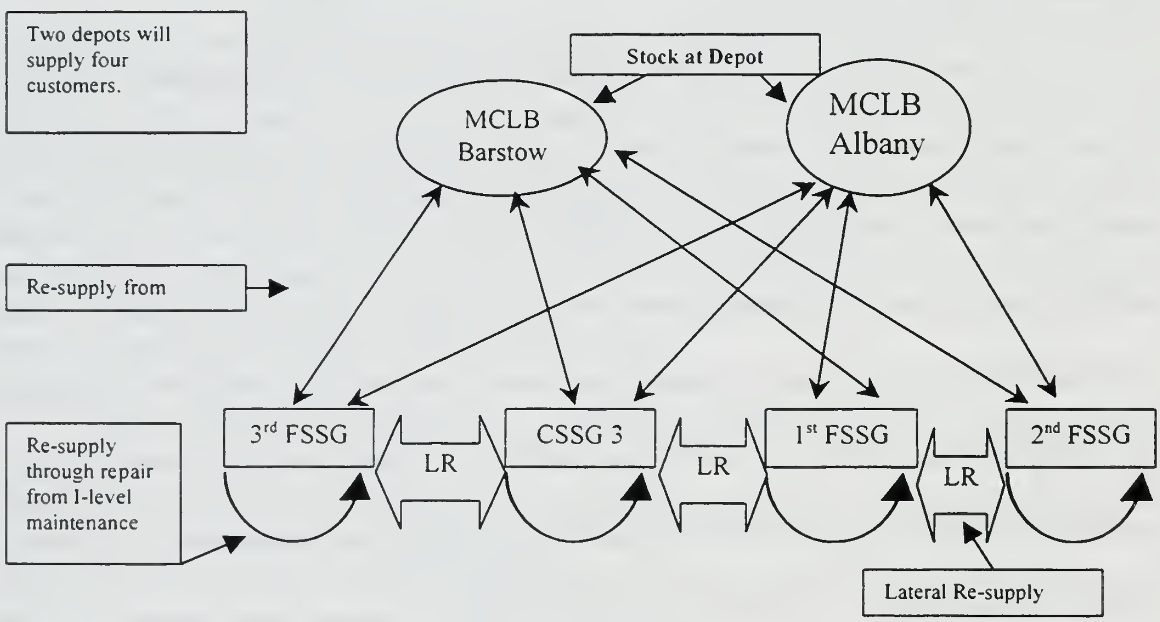

Figure 5. Flow of Material With Lateral Re-supply

We developed our model in a simulation language, Arena with graphics animation. In Arena, simulation models are built by placing modules in a working area of the model window, providing data for these modules, and specifying the flow of entities through the modules. The module defines the underlying logic that is applied

when an entity is directed to the module, as well as the associated graphical animation, to depict the module's activities during a simulation run [Ref. 29].

1. Inventory Logic

We consider a base stock inventory control policy in which a replenishment order is submitted at the time of demand. We assume that the demand each day is Poisson distributed and independent from day-to-day. Figure 6 provides an overview of the inventory logic at a base.

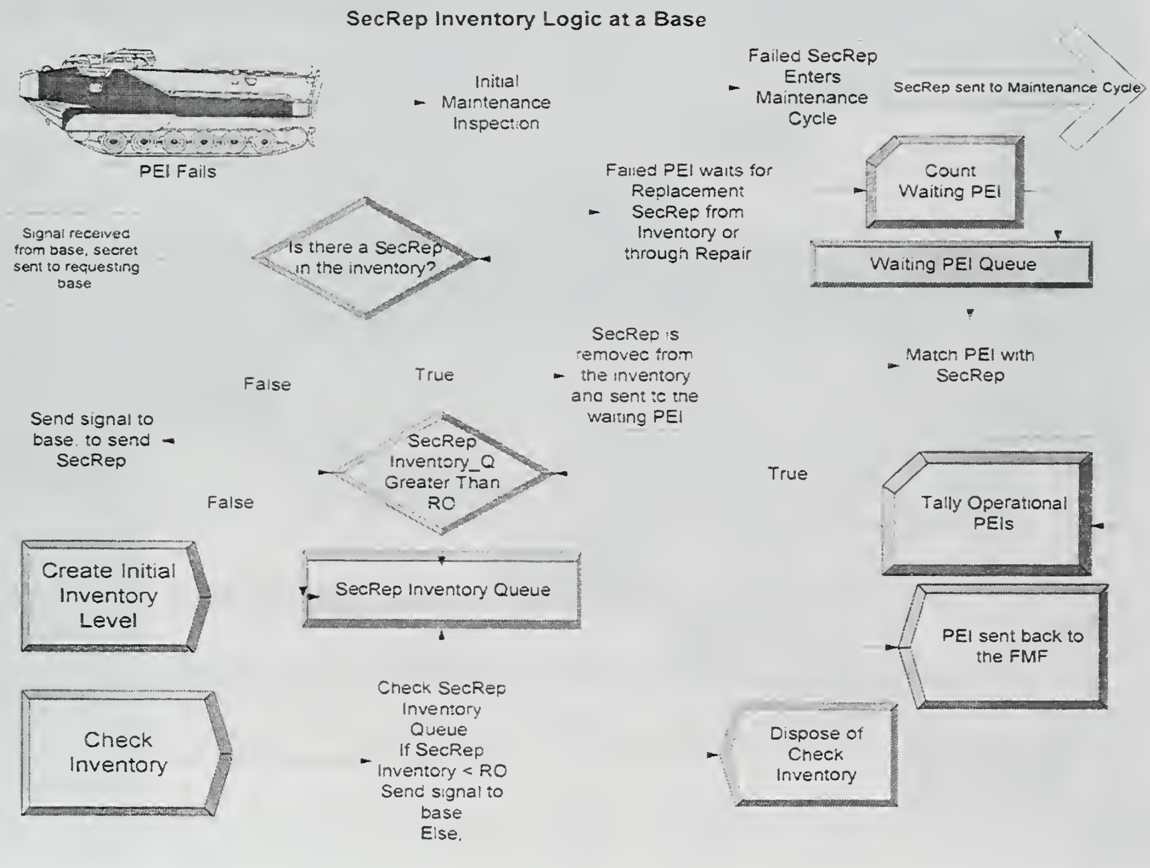

Figure 6. Overview the Inventory Logic at a Base

We assume the lead-time between the placement of an order and its arrival to the required base follows routine shipping delays. Table 3.1 describes the lead-time between bases for routine shipments (in the lower triangle) and the distance between two locations (in the upper triangle). Appendix B provides the service standards from each base within the 48 contiguous states. Table 3.2 describes the shipping cost per pound as provided by Overnight Transportation, an approved government LTL carrier.

Lead-Time	CAMP LEJUNE, NC	ALBANY, GA	BARSTOW, CA	CAMP PENDLETON, CA	LONG BEACH, CA	OAKLAND, CA	SAN FRANCISCO, CA	SAN DIEGO, CA
CAMP LEJUNE, NC		572	2558	2666	2693	2971	2978	2631
ALBANY, GA	2		2210	2206	2253	2619	2627	2171
BARSTOW, CA	5+	5+		164	132	409	417	180
CAMP PENDLETON, CA	5+	5+	2	Days	71	455	463	40
LONG BEACH, CA	5+	5+	1	1	Miles	395	403	111
OAKLAND, CA	5+	5+	3	3	2		8	495
SAN FRANCISCO, CA	5+	5+	3	3	2	1		503
SAN DIEGO, CA	5+	5+	2	1	3	3	3	

(Note: For shipments to Hawaii add 10 day to the lead-time from Long Beach. For shipments to Okinawa, add 21 days to the lead-time from Long Beach)

Table 3.1 Lead Time Between Bases [Ref. 27]

We create an initial inventory queue to replicate current inventory levels at each base and check the inventory queue throughout the simulation. After each demand for a SecRep, a signal is sent to the depot to send a replacement SecRep if the inventory queue falls below authorized allowances. As the PEIs begin to fail during the simulation, the simulated FMF unit conducts an initial maintenance inspection and prepares to send the

PEI to the IMA. We assume that all failed PEIs are sent to the IMA and the delay time from the unit to the IMA is the same for all bases. Once the PEI arrives at the IMA, the failed SecRep, which is an engine in our case, is removed and enters the maintenance cycle. The PEI enters a wait queue until an available SecRep is matched to the required PEI. At the same time the PEI enters the wait queue, a system inventory check is conducted within the simulation. First, the SecRep inventory level at the base is checked. If there are no SecReps on hand, the PEI continues to wait until a SecRep is made available through repair or the RIP's stock has been replenished from another source of supply. In the case of lateral re-supply, a search is conducted at the other bases for the required SecRep. If the SecRep is available at another base, it is transported to the required base. The delay time from each base is based on the times in Table 3.1.

Cost Per lbs	CAMP LEJEUNE NC	ALBANY GA	BARSTOW CA	CAMP PENDLETON CA	LONG BEACH CA	OAKLAND CA	SAN FRANCISCO CA	SAN DIEGO CA
CAMP LEJEUNE, NC		572	2558	2666	2693	2971	2978	2631
ALBANY, GA	$0.46		2210	2206	2253	2619	2627	2171
BARSTOW, CA	$0.96	$0.90		164	132	409	417	180
CAMP PENDLETON, CA	$0.88	$0.71	$0.31	**Cost**	71	455	463	40
LONG BEACH, CA	$0.75	$0.77	$0.25	$0.15	**Miles**	395	403	111
OAKLAND, CA	$1.01	$0.99	$0.40	$0.56	$0.38		8	495
SAN FRANCISCO, CA	$1.05	$0.97	$0.51	$0.48	$0.25	$0.25		503
SAN DIEGO, CA	$0.64	$0.85	$0.39	$0.25	$0.43	$0.60	$0.45	

Table 3.2 Shipping Cost Per Pound as Provided by Overnight Transportation

Once the PEI is matched to the required SecRep, the PEI is sent back into the system and counted. We track the operational availability at each location by determining the number of failed PEIs at the base divided by the total number of PEIs. Table 3.3 provides the PEIs selected for our evaluation as well as the location and number of PEIs available at each location [Ref. 30].

TAMCN	PEI	I MEF	II MEF	III MEF
E0796,E0846,E0856	Assault Amphibious Vehicle	247	237	66
D1059	Truck, Cargo, 5-ton	1019	962	682
D0209	Power Unit, LVS	356	334	214
D1158	Truck, Cargo, HMMWV	1727	1751	1159

(Note: I MEF is located in Camp Pendleton, CA; II MEF is located in Camp Lejeune, NC; and III MEF is located in Okinawa, Japan and Hawaii)

Table 3.3. Principal End Items (PEIs) and Their Locations [Ref. 30]

We use the operational availability at each location to compare the effects of the two different inventory policies. Given the PEIs listed in Table 3.3 and the levels of inventory within the supply chain, we determine the operational availability for the base scenario by simulating demand at each location. Table 3.4 gives the actual inventory levels and RO levels for each base. We use these as the basis for our simulation [Ref. 19, 20, 21, 22].

For the second scenario, we determine the initial operational availability at each base and then we reduce the inventory systematically at each base until the operational availability matches the A_o from the first scenario. We use the same string of random numbers generated from our first scenario and apply those numbers to our second

scenario to ensure that our change in inventory policy is the only event that affects the operational availability.

Location	Item	NSN	Weight (lbs)	Cubic Inches	Cost	Exchange Price	Allowance	RO	OH	In Repair
1st FSSG	AAV Engine	2815011408799	3484	150	$51,994.54	$35,347.61	53	30	23	16
2nd FSSG	AAV Engine	2815011408799	3484	150	$51,994.54	$35,347.61	72	72	14	37
3rd FSSG	AAV Engine	2815011408799	3484	150	$51,994.54	$35,347.61	20	16	12	3
CSSG 3	AAV Engine	2851501140879	3484	150	$51,994.54	$35,347.61	5	4	1	0
Albany	AAV Engine	2851501140879	3484	150	$51,994.54	$35,347.61	-	-	47	-
Barstow	AAV Engine	2815011408799	3484	150	$51,994.54	$35,347.61	-	-	84	-
1st FSSG	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	13	13	5	8
2nd FSSG	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	21	21	7	8
3rd FSSG	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	15	21	0	9
CSSG 3	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	6	6	1	2
Albany	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	-	-	23	-
Barstow	5-Ton Engine	2815001780268	4255	118.7	$22,322.00	$12,723.54	-	-	13	-
1st FSSG	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	10	10	1	10
2nd FSSG	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	13	13	4	10
3rd FSSG	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	7	9	7	0
CSSG 3	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	7	4	3	1
Albany	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	-	-	37	-
Barstow	LVS Engine	2815011867251	2875	150	$27,609.00	$27,609.00	-	-	28	-
1st FSSG	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,660.00	45	45	9	11
2nd FSSG	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,666.00	63	52	23	14
3rd FSSG	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,666.00	38	46	15	18
CSSG 3	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,666.00	15	15	2	2
Albany	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,666.00	-	-		-
Barstow	HMMWV Engine	2815014396664	650	15.87	$6,666.00	$6,666.00	-	-		-

Table 3.4 Supply Chain Information [Ref. 19, 20, 21, 22]

2. Repair Process Logic

The repair process runs every period, in our case daily, to determine if the principal end item (PEI) has failed. As the PEIs begin to fail, a parallel process occurs

within the simulation. The failed SecRep is removed from the PEI and placed into the repair process, while the PEI enters a wait queue and searches for a replacement SecRep according to the inventory logic. We assume that only one SecRep has failed per PEI. As the SecRep enters the repair process, the simulated IMA determines if the SecRep can be repaired at its level or if the item is beyond repair. We assign probabilities that a SecRep can be repaired by the IMA, must be sent to the depot for repair, or must be disposed of based on the washout percentage for the SecRep at the base. The washout percentage is the number of SecReps not repaired at the IMA divided by the total SecReps that arrived for repair. Table 3.5 describes the maintenance characteristics of each SecRep [Ref. 19, 20, 21, 22].

Location	Item	MTBF	Repaired By IMA	Sent to DRMO	Sent To Depot	TAT (Min-Max) in days
1st FSSG	AAV Engine	50	95%	1%	4%	3-120
2nd FSSG	AAV Engine	50	77%	2%	21%	3-120
3rd FSSG	AAV Engine	50	96%	1%	3%	2-180
CSSG 3	AAV Engine	50	97%	1%	2%	2-180
1st FSSG	5-Ton Engine	720	97%	1%	2%	3-120
2nd FSSG	5-Ton Engine	720	62%	4%	34%	3-120
3rd FSSG	5-Ton Engine	720	97%	1%	2%	2-180
CSSG 3	5-Ton Engine	720	97%	2%	1%	2-180
1st FSSG	LVS Engine	400	95%	1%	5%	3-120
2nd FSSG	LVS Engine	400	93%	1%	6%	3-120
3rd FSSG	LVS Engine	400	95%	1%	5%	2-180
CSSG 3	LVS Engine	400	95%	1%	5%	2-180
1st FSSG	HMMWV Engine	500	84%	6%	14%	3-120
2nd FSSG	HMMWV Engine	500	89%	2%	9%	3-120
3rd FSSG	HMMWV Engine	500	95%	1%	4%	2-180
CSSG 3	HMMWV Engine	500	91%	1%	8%	2-180

Table 3.5 Maintenance Characteristics of Each SecRep [Ref. 19, 20, 21, 22]

We count the number of SecReps disposed from each base. We assume that the SecRep is sent to a local Defense Reutilization and Marketing Service (DRMS) and transportation cost is minimal. If the SecRep has been determined to be beyond the IMA capability of repair and sent to the depot, we track the number of times the SecRep is sent to the depot in order to calculate transportation costs. We assume the depots have an infinite source of SecReps and that the TAT follows a uniform distribution with a minimum of 30 days and a maximum of 45 days [Ref. 31]. If the IMA repairs the SecRep, parts are ordered for the repair and it is delayed until the parts arrive. The delay time is based on the supply support capability of the local SMU. We assign a probability that the supporting SMU will have the required parts based on the equipment repair order (ERO) fill rate of the local SMU [Ref. 28]; that is, the percentage of critical EROs for which all high-priority requisitions were immediately available from the local supply. We estimated the average ERO fill rate for I MEF at 37.5%, II MEF at 16%, and III MEF at 25.7% based on the data from the Marine Corps's Precision Logistics Web site [Ref. 28].

In practice, a SecRep is repaired at the IMA as soon as all of the required parts have been received. We use the RCT for the item to determine how long the SecRep is delayed due to repair. We were unable to obtain data on the RCT for each of the SecReps we selected; instead, we used the overall average RCT of each IMA. We assume a Poisson distribution and with mean cycle times for I MEF of 30.3 days, II MEF 42 days, and III MEF 44.8 days [Ref. 28].

Upon completion of repair, the SecRep moves to a decision module to determine whether or not the SecRep is still required. If the SecRep is still required it is matched to a PEI, tallied, and sent back to the system. If the SecRep is no longer required, because the PEI was matched with a SecRep from local stocks or through re-supply from the depot in the case of our first scenario or through lateral re-supply from another base in the case of our second scenario, the SecRep is sent the local RIP inventory. In reality, the repaired SecRep would be redistributed if local on hand amounts exceed authorized allowances. Figure 7 provides an overview of the repair process logic used in the simulation.

B. MODELING DEMAND

We model demand by using the failure rate of the PEI, or in our case the mean time between failure (MTBF) of an engine. The MTBF is the length of time that an item is available to perform its intended function [Ref. 10]. We estimated the MTBF of the items through interviews with I-level and depot level maintenance personnel. Table 3.5 describes the MTBF for our selected SecReps. As the PEIs begin to fail within the simulation, a demand is created for a SecRep. We estimate the length of time that each PEI is operational at two hours per day with a total of 730 hours of usage per year. It is important to note that our assumptions of the MTBFs and our estimated usage of PEIs within the simulation directly affect the expected savings achieved within the simulation. The higher the usage of the PEIs during the simulation the greater the number of failures during our simulated two-year period. Our estimate of how often a PEI is used is based

on the author's experience, because the Marine Corps does not record actual usage or MTBF data from exercises or daily operations.

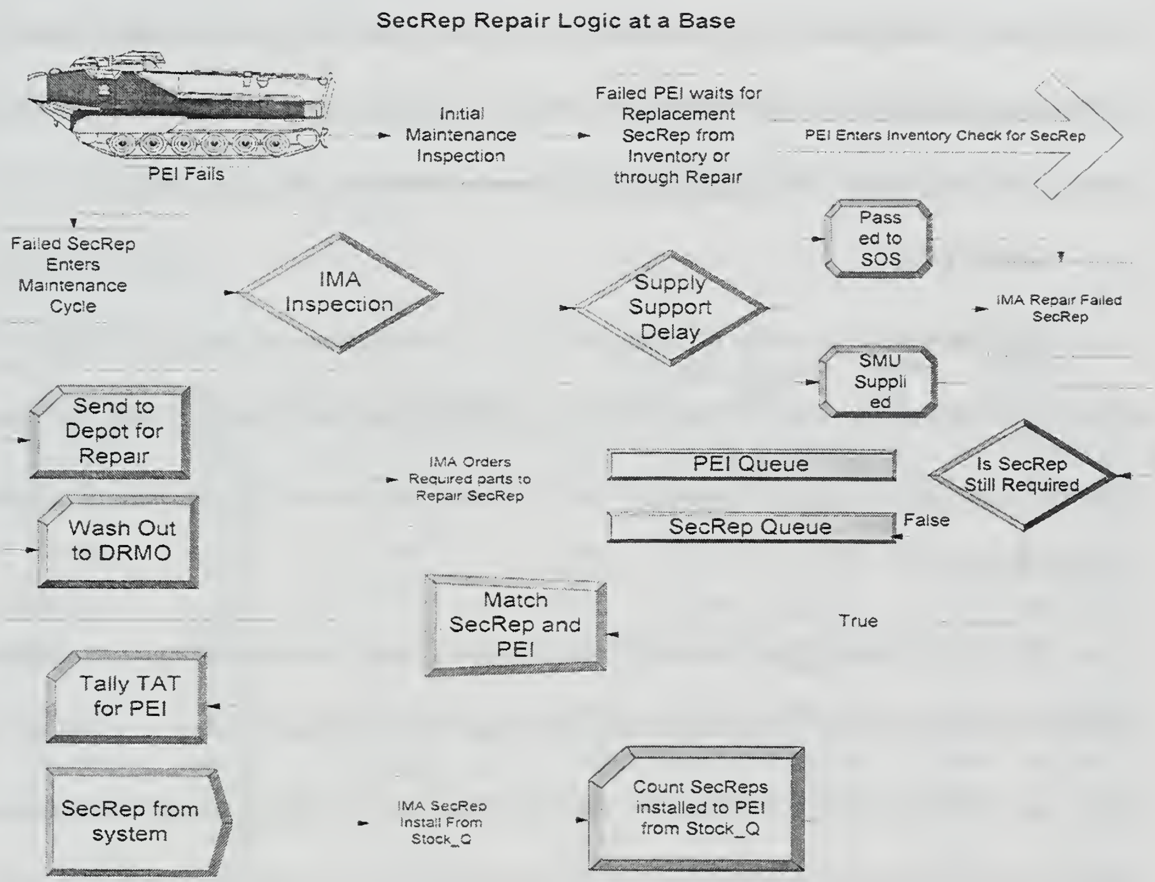

Figure 7. Overview of the Repair Process Logic at a Base

C. WEAKNESS OF THE MODEL

Because multi-echelon systems are difficult to model and solve analytically, we decouple the maintenance process, supply process, and inventory search logic as separate

operations and link the modules. This simplified method does not account for the dependency of data used to make decisions throughout the supply chain. For example, if all the participants within the supply chain have full access to all information with respect to SecReps, consideration may be given to a location that has a requirement based on operational commitments vice training or routine replenishments. Our model in essence uses a greedy algorithm that transfers the SecRep on a first come first served basis.

D. RESULTS

We performed two runs of 50 replications of each inventory policy to simulate 24 months of demand. Scenario 1 is an inventory policy where we re-supply with no lateral transfer, and scenario 2 is an inventory policy where we re-supply with lateral transfer between bases.

First, we stocked each base with the inventory level corresponding to its RO and simulated demand with no lateral transfer. Note that the simulated A_o does not reflect the actual A_o within the FMF because we do not consider the effects of cannibalizations, expedited shipments of required parts, actual mean time between failures for the SecReps, and operational conditions and requirements that may exist within the FMF.

Next, we repeated the experiment with lateral transfer for each PEI, and recorded the average A_o at each base. Then we repeatedly changed the RO at each base and ran the experiment until we finally matched the average A_o from the no lateral transfer case. Table 3.6 shows the results. Notice that we were able to reduce the SecRep stock at most locations, but for bases that frequently re-supplied other bases, the stock level had to be increased to maintain the same level of A_o.

Under the current decentralized system, holding cost is not a factor or consideration in determining RO levels. The U.S. Navy considers holding cost as 21% of the cost of goods for repairable items and 23% for consumable items [Ref. 11]. Using 21% holding cost rate, we estimate the holding cost for the SecReps we selected to be $2,047,946 per year (See Table 3.6). Our results indicate that a lateral re-supply policy reduces holding costs for the items we selected by $177,593, based on a 21 percent holding cost rate.

Location	Item	Current RO Scenario 1	Ao	Scenario 2	Ao	New Inventory Cost	Old Inventory Cost	New Annual Holding Cost	Old Annual Holding Cost
1st FSSG	AAV Engine	30	76%	34	76%	$1,767,814	$1,559,836	$371,241	$327,566
2nd FSSG	AAV Engine	72	82%	62	82%	$3,223,661	$3,743,607	$676,969	$786,157
3rd FSSG	AAV Engine	16	96%	14	96%	$727,924	$831,913	$152,864	$174,702
CSSG 3	AAV Engine	4	81%	6	81%	$311,967	$207,978	$65,513	$43,675
1st FSSG	5-Ton Engine	13	90%	11	90%	$245,542	$290,186	$51,564	$60,939
2nd FSSG	5-Ton Engine	21	94%	18	94%	$401,796	$468,762	$84,377	$98,440
3rd FSSG	5-Ton Engine	21	91%	17	91%	$379,474	$468,762	$79,690	$98,440
CSSG 3	5-Ton Engine	6	84%	7	84%	$156,254	$133,932	$32,813	$28,126
1st FSSG	LVS Engine	10	86%	9	86%	$248,481	$276,090	$52,181	$57,979
2nd FSSG	LVS Engine	13	85%	8	85%	$220,872	$358,917	$46,383	$75,373
3rd FSSG	LVS Engine	9	87%	7	87%	$193,263	$248,481	$40,585	$52,181
CSSG 3	LVS Engine	4	80%	3	80%	$82,827	$110,436	$17,394	$23,192
1st FSSG	HMMWV Engine	45	87%	43	87%	$286,638	$299,970	$60,194	$62,994
2nd FSSG	HMMWV Engine	52	88%	44	88%	$293,304	$346,632	$61,594	$72,793
3rd FSSG	HMMWV Engine	46	89%	41	89%	$273,306	$306,636	$57,394	$64,394
CSSG 3	HMMWV Engine	15	84%	14	84%	$93,324	$99,990	$19,598	$20,998
Total		377		338		$8,906,448	$9,752,128	$1,870,354	$2,047,947

Table 3.6 Results of the Simulation

Engine	Number of Transfers	Avg Cost	Total Cost
AAV	27	$3,150	$85,050
5-Ton	20	$4,363	$87,260
LVS	16	$2,721	$43,536
HMMWV	21	$425	$8,925
Total	84	$10,659	$224,771

Table 3.7 Number of Transfers and Cost

Engine	Routine Shipments under Scenario 1	Avg Cost	Total Cost	Routine Shipments under Scenario 2	Avg Cost	Total Cost
AAV	23	$2,895	$66,585	16	$2,745	$43,920
5-Ton	21	$4,125	$86,625	12	$3,120	$37,440
LVS	18	$1,985	$35,730	10	$1,985	$19,850
HMMWV	22	$401	$8,822	14	$401	$5,614
Total			$197,762			$106,824

Table 3.8 Routine Transportation Cost

Total transportation costs for the lateral transfer policy were significantly higher. We estimated average costs for lateral transfers and routine shipments (see Tables 3.7 and 3.8), based on the cost per pound listed in Table 3.2. The average routine shipping costs are less because more shipments in scenario 2 are made to 1st FSSG and 2nd FSSG from the depots, and transportation cost to these FSSGs is lower than the cost to ship to CSSG-3 and 3rd FSSG. The average transfer costs are higher because distant locations were the primary beneficiary of lateral transfers.

We estimate total shipping cost for the no lateral transfer case to be $197,762. Total transportation cost for the case with lateral transfers was $331,595, including

$224,771 just for lateral transfers. The combined inventory holding and transportation cost savings for the lateral transfer case were only $43,760 annually.

Our results also suggest that items with a higher failure rate would potentially achieve less savings, which supports Sherbrooke's claim [Ref. 10: p. 226] that lateral re-supply has a greater impact when demand rates are low. In Table 3.6, AAV engines did not realize the same level of stock reduction that the 5-ton, HMMWV, and LVS engines did. We were able to reduce AAV engine inventory by only 4.9%, compared to 13.1%, 10.1% and 25% for 5-Ton, HMMWV and LVS engines, respectively.

Additionally, Sherbrooke suggests that the benefits of lateral re-supply are overstated and argues that lateral re-supply will have a beneficial impact only when the transfer time is one-fourth or less of the base repair time. He contends that the base can change its repair priorities and repair an item, if it has repair parts, in less than the average repair time. He concludes that lateral re-supply will provide little benefit when items are base-repairable. Over 90% of the items we selected are repaired at the base, which may contribute to the marginal financial benefits of a centralized system within our model. We also do not consider that each IMA and the SMU can shift resources in order to provide the required SecRep to the supported unit.

We believe that our model does not show a significant cost savings between the two inventory policies for at least two reasons:

1. The geographical layout of the supply chain for SecReps is not propitious to a lateral transfer policy, because the nodes within the supply network cover half the globe. From 1st FSSG in Camp Pendleton, California to 2nd FSSG in Camp

Lejeune, North Carolina is more than 3000 miles; from Camp Pendleton to Okinawa, Japan is more than 12,500 miles; and from Camp Pendleton to Hawaii is more than 5,700 miles. Considering that most SecReps weigh a considerable amount, the shipping costs associated with a lateral transfer policy diminish the benefits gained from reduced inventory levels and lower holding costs. It might be the case that SecReps weighing less than appropriate limits can be shipped via air relatively inexpensively, making the lateral transfer policy more attractive.

2. Because we did not optimally position the inventory among bases, we may have underestimated the benefits of a centralized inventory system that allows lateral re-supply. By not optimally positioning where the SecReps should be maintained within our model, we essentially account for transfer costs that may not have occurred had the SecReps been positioned to minimize transportation costs. Although our results show a slight financial advantage for the lateral transfer policy, it might be the case that significantly more savings could be obtained with optimally positioned stock.

E. OTHER ISSUES

There are other potential benefits of a centralized system. For example, maintenance and supply personnel at certain locations may be reduced because of lower inventory levels. With lower inventory levels, there are fewer items to manage and maintain. Savings are possible in less maintenance of embarkation boxes, conducting fewer routine technical inspections of SecReps, and less packaging and corrosion prevention.

Kang [Ref. 36] suggests that centralization enables a company to maintain tight control while consolidating shipments and lowering cost. He also sites a 1993 University of Maryland survey of 20 companies seeking best logistics practices, which found that all of them had centralized their strategic logistics management function in proximity to their corporate center. Although most of the companies cited do not move large items that are expensive to transport, they all cited increased control, improved efficiencies, and lower costs as the primary motivations behind their centralization philosophy. Mullinix [Ref. 37] suggests that the majority of Fortune 500 companies that have moved to centralization agreed that hardware, people, and maintenance are more economically used in a centralized order-management environment than in a decentralized one. He indicates that they believe that centralization facilitates integration of order management with other operating systems, such as production planning, scheduling, transportation management, and warehouse management. He also indicated that the companies reported that centralization results in better customer service and enhances customer perception that a company is "easy to do business with."

There are also areas for concern. First, the Marine Corps must specify an organizational structure to centrally manage SecRep inventories. Questions include: Will all inventory decision-making power be moved to MCLB Albany, or will the bases continue to have limited authority? If they will, how much? Some decentralized systems are organized as "virtual organizations", which Sandhoff [Ref. 33] defines as a network operating on the principle of self-organization. Central to Sandhoff's concept of a virtual organization is that the organizational-structure is replaced by new information and

communication technologies (ICT), trust, and open communication. He suggests that loosely linked nodal points within the network replace the formal structure in a virtual organization and that all actors have equal participation.

An advantage to this type of structure is that information about all of the elements and participants becomes an asset to the whole organization. Successful process and systems can quickly be exploited and horizontally and vertically disseminated throughout the organization. Additionally, information sharing is a key success factor within a virtual organization. Ishaya [Ref. 34] suggests that while virtual organizations present laudable opportunities, they also present a number of uncertainties and challenges. He indicates that this has led to the argument that trust may not be possible in virtual organizations. The movement to a virtual float concept might require levels of trust and information sharing that do not currently exist. Additionally, new methods of communication and information systems would probably have to be established to support a virtual organization.

Kang [Ref. 36] indicates that in the commercial sector, inventory management personnel typically remain in the same job for several years, and often stay in the same location for their entire career. He also indicates that a similar situation exists for some DoD civilian inventory managers. He suggests that this is not the case for operating forces, with a 25% personnel turnover rate each year. He argues that because military supply personnel rotate through different tasks in order to acquire a variety of skills, they do not develop in-depth inventory management experience. While centralizing inventory

management in MCLB Albany, GA would capitalize on the experience of civilian inventory managers, there are potentially negative effects on their ability to manage:

- Under a centralized inventory system, information available to the inventory managers would be limited, such as when exercise and training evolutions are planned, and how past exercises and operations affected demand for SecReps. The demand for a SecRep is a function of the operating hours of the PEI. As PEIs are utilized more frequently during exercises or training evolutions, the failure rate for SecReps usually increases. Although planned operating hours for equipment is currently not tracked within the Marine Corps, each MEF is able to estimate planned usage of equipment based on local operations and training plans. Without systems or processes in place to determine planned usage, a centralized inventory manager might not be able to forecast planned usage of PEIs as would a local inventory manager.
- A centralized inventory manager might not have access to local maintenance and supply personnel capabilities, and might not be able to account for rotation and training issues [Ref. 6, 26] because he does not possess "local knowledge".
- Finally, a centralized inventory manager could have more difficulty determining the accuracy of the data reported by the MEFs, traditionally a weak spot for Marine Corps supply support.

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IV. CONCLUSIONS AND RECOMMENDATIONS

In a world characterized by accelerating change, the challenge becomes one of sorting, selecting and casting meaningful change initiatives. We believe that simulation tools can help to validate new concepts and provide a foundation for the strategic, operational, and tactical direction of Marine Corps Logistics. We provided an overview of inventory issues and policies, presented our research problem, and stated the objective of the thesis within Chapter I. We started out by describing the direction of the DoD with respect to inventory management and the Marine Corps virtual float concept.

Additionally, we discussed the current supply chain for SecReps and presented an overview of the basic functions of the repairable issue point (RIP). We described the demand based sparing (DBS) methodology currently used to determine inventory levels and discussed other relevant studies and research with respect to repairable inventory management. We showed that the Marine Corps has started to progress towards readiness-based sparing (RBS) by chartering studies through the Center for Naval Analyses (CNA), but will have difficulty implementing RBS due to inaccurate data collection. We presented the ideal that simulation and modeling of the Marine Corps' supply chain can be used to evaluate different policies. We show that a centralized, lateral transfer policy might not provide significant cost savings, when considering both inventory and transportation costs.

A. CONCLUSIONS

Using a simulation model, we considered trade-offs associated with centralized inventory management, stock reduction, and transportation cost. Specifically, we asked what overall inventory policy satisfies demand while minimizing inventory holding cost and transportation cost. We believe that the Marine Corps should not expect large savings from a virtual float operating with a lateral transfer inventory policy. For the items we selected, we estimated a modest annual savings of no more than $50,000.

We believe the unimpressive savings are due primarily to two factors. First, lateral re-supply is expensive for large items in the Marine Corps system, because bases are far apart. For our test items, this greatly diminished the benefits of reduced inventory levels. Second, we did not optimally position stock among bases. It is possible that greater savings are possible with better placement of inventory.

We also argued that a virtual float has significant issues that should be resolved prior to implementation, such as: Are information systems in place to support centralized management of repairables? Will a virtual float simply function as a centralized organization or function as a virtual organization? Are there enough resources and capacity within the supply chain to support lateral transfer? and, What will be the measure of effectiveness of a virtual float? Overall system readiness or readiness based on the individual location?

B. RECOMMENDATIONS

1. Do not implement a "Virtual Warehouse" concept based on potential financial savings.

Our research showed that the potential financial savings of lateral transfers are marginal at best, due primarily, we believe, to the great distances, and therefore high transportation costs between Marine Corps bases. The decision to implement a virtual warehouse concept should be based on the expected long term benefits of centralization that commercial firms currently receive, e.g., reduced overhead support structure for personnel, finance, automated data processing (ADP) systems, and integrating logistics within strategic policy.

2. Determine the level of resources and capacity at each location within the supply chain.

Our research supports that overall inventories may be reduced for selected items. However, we also showed that some locations might function as a sort of distribution center to other, more distant bases, and therefore would have *more* inventory. Before implementing a virtual float, the resources at each location should be analyzed to determine if there is enough capacity to support a virtual float.

3. Incorporate transportation cost and holding cost within Marine Corps policy to improve logistics decision making.

Without accounting for these costs, sub-optimal decisions are certain. In our case, not accounting for transportation costs would suggest that lateral transfer is an attractive

policy without reservation. Our findings suggest that accounting for both costs is vital to making a proper decision on whether or not to centralize.

4. Develop an optimal stock-positioning model.

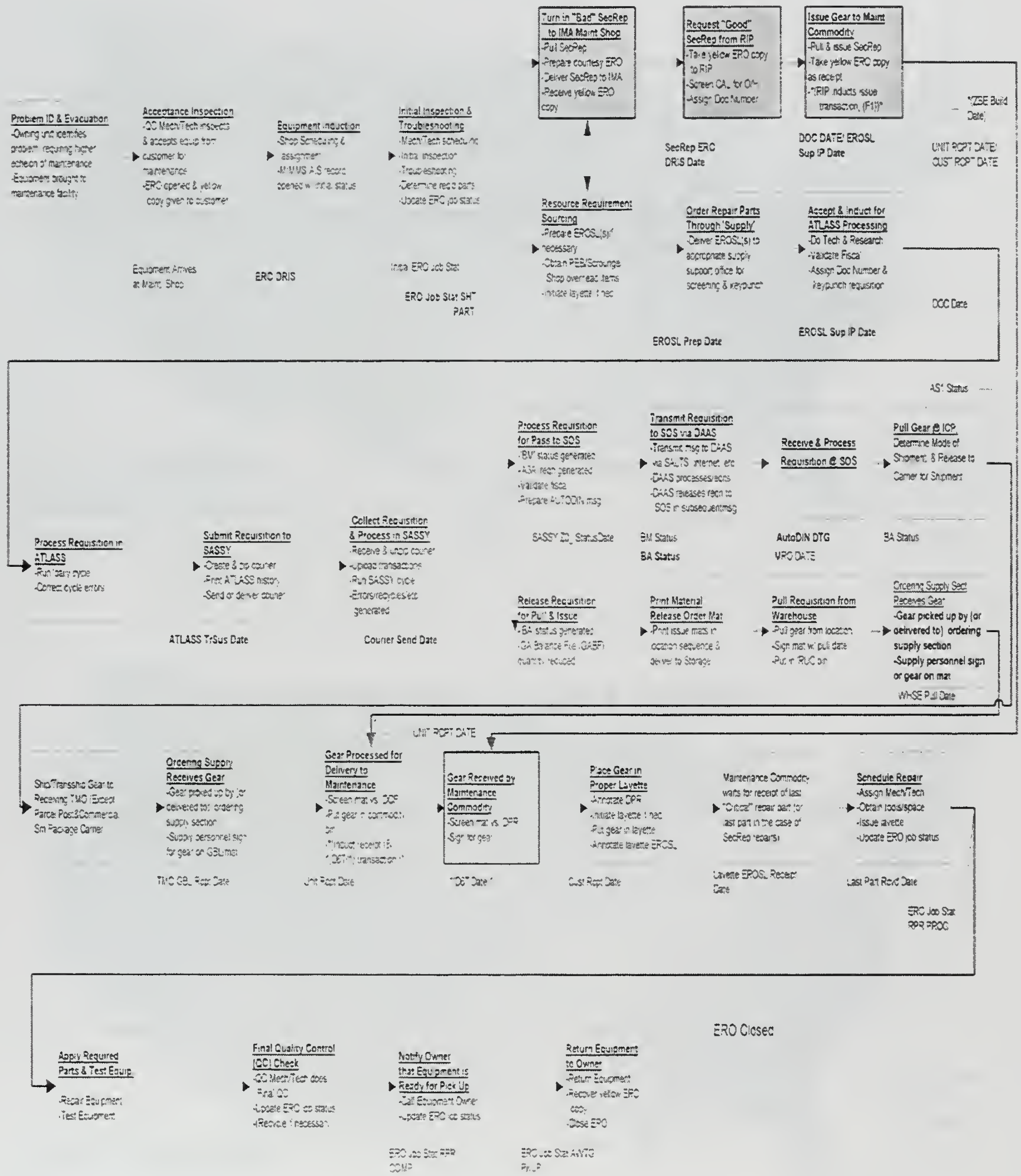
Developing an optimal stock-positioning model would enhance the potential benefits a virtual float. Additionally, an optimal stock-positioning model should consider A_o and readiness and provide the basis for future inventory applications.

C. FUTURE

Further research should consist of determining the effects of RCT at each location and how that affects that overall system. As the RCT decreases, does the A_o increase? and by how much? Should the Marine Corps establish centers of excellence or focused factories at each location to reduce RCT? For example, 1st FSSG may establish a center of excellence in AAV engine repair and consequently reduce their RCT significantly. All AAV engines would be sent to 1st FSSG, as they become the primary distribution center for AAV engines.

Finally, further research should define the characteristics of a virtual float. Who will be the participants? How will information flow within the supply chain? Will all RIPs have equal claim to any SecRep required within the supply chain? and What will be the standard to deliver the required SecReps? 48 hours? 72 hours? We suggest that the relationship between the central item managers and the FMF is dependant on clearly defined expectations of service and is therefore a key success factor for a virtual float.

APPENDIX A. SUPPLY AND MAINTENANCE EFFORT



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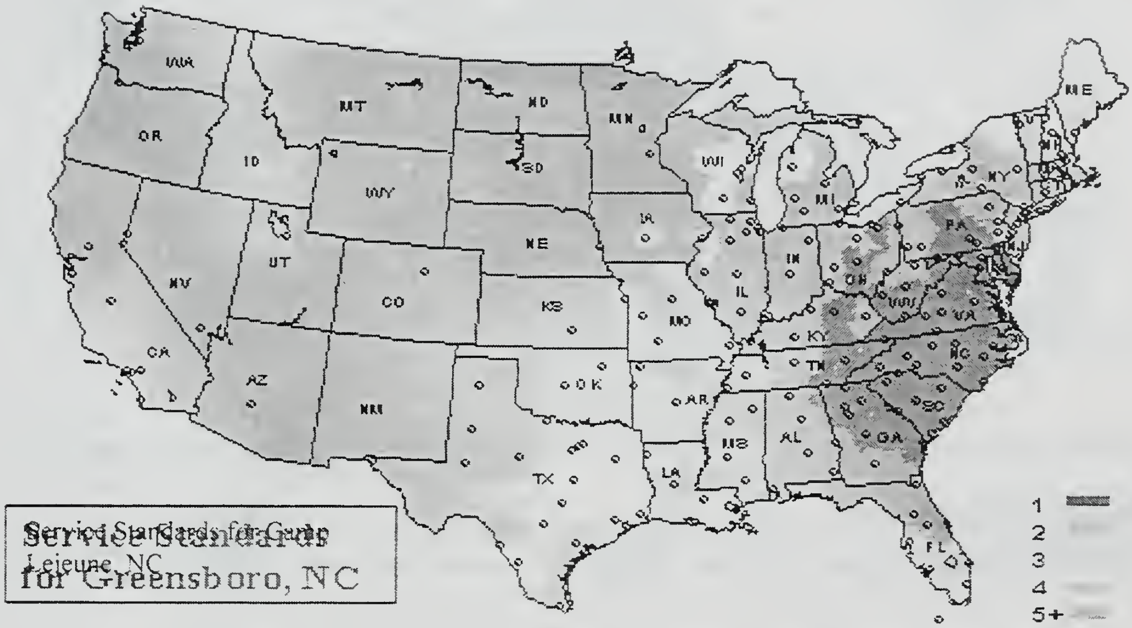
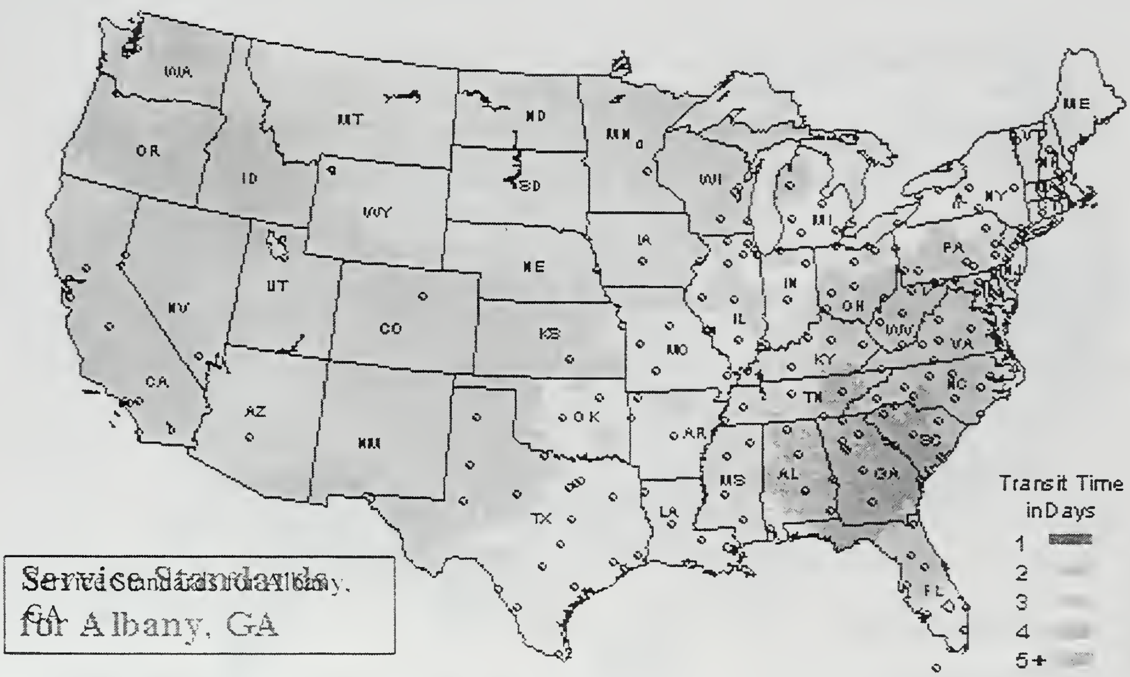
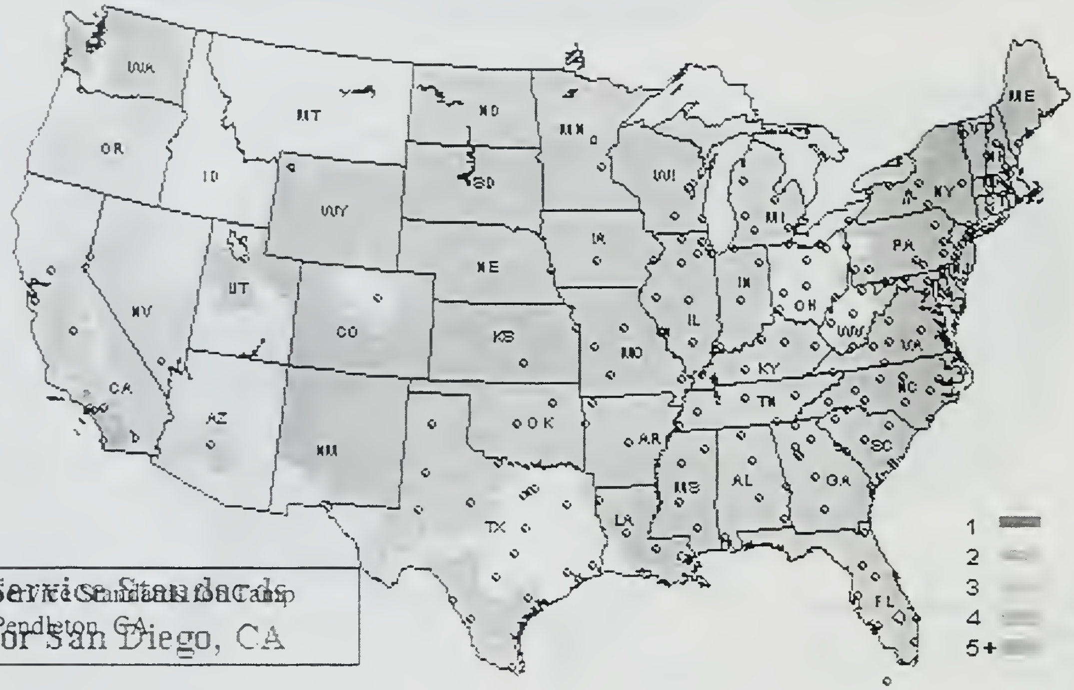
APPENDIX B. SERVICE STANDARDS FOR OVERNIGHT TRANSPORTATION

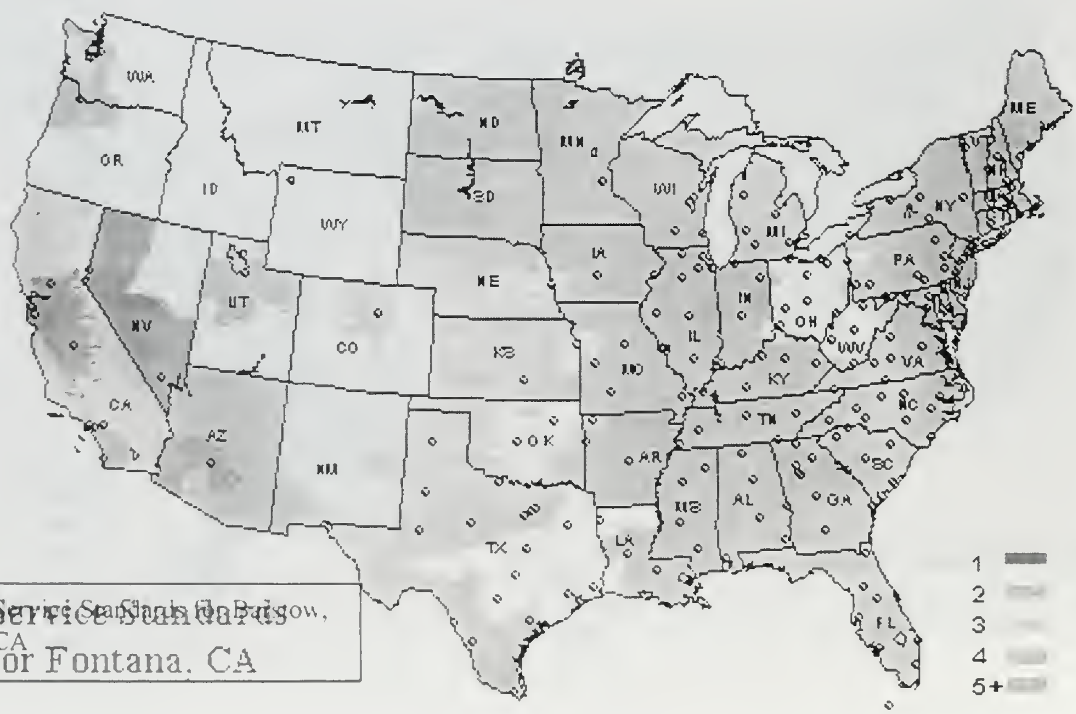






Service Standards for Camp Pendleton, CA

Service Standards for San Diego, CA



Service Standards for Barstow, CA

Service Standards for Fontana, CA

LIST OF REFERENCES

1. DoD Logistics Strategic Plan FY 1998.

2. DoD Logistics Strategic Plan FY 2000.

3. Rudolph, M.E., *Virtual Float Point Paper,* Oct 1998.

4. Stuart, D.E., "Establishing the Virtual Warehouse," M*anufacturing Science and Engineering ASME 1995* pp.1299-1302.

5. MCO P4400.151B. Intermediate Level Supply Management Policy Manual, 1993.

6. FSMAO-3, *OST and RCT Study of Combat Service Support Group-3*, 1996.

7. MCO 4400.120, Joint Regulations Governing the use and Application of Uniform Source Maintenance and Recoverability Codes, 1992.

8. Telephone Interview with Mr. Eddie Gleaton, Maintenance Data Analysis Office (Code 824-2) Operations Division, Marine Corps Logistics Base, Albany, GA on March 22, 2000.

9. UM 4400.123, FMF SASSY Management Unit Procedures, 1984.

10. Sherbrooke, C.C, *Optimal Inventory Modeling of Systems, Multi-Echelon Techniques*, pp.1-73, John Wiley & Sons, New York, 1992.

11. NAVSEALOGCEN, "Readiness Engineering Overview", [http://www.nslc.fmso.navy.mil/EngD&A/ReadEng/rehome.htm], Jan, 1999.

12. NAVSEA TE660-AA-MMD-010, TIGER User's Manual Version 8.21, Sep. 1987.

13. Archibald, G., Karabakal, N. and Karlsson, P., "Supply Chain vs. Supply Chain: Using Simulation to Compete Beyond the Four Walls," *Proceedings of the 1999 Winter Simulation Conference*, G.W. Evans et al. (eds) pp.1207-1214, 1999.

14. Hale, A., *Improving the Marine Corps War Material Requirement (WMR) Process: Phase 1*, Center for Naval Analyses Report CRM 97-109, pp.15-18, October 1997.

15. Williamson III, W., *A Primer on Using Readiness-Based Sparing to Determine Marine Corps Class IX Requirements*, Center for Naval Analyses Report CRM 98—86.09, 1998.

16. Penrose, C.B, *Implementing Availability- Based Sparing in the Marine Corps*, Master's Thesis, Naval Postgraduate School, Monterey, California, September, 1998.

17. Hicks, D.A., "A Four Step Methodology For Using Simulation and Optimization Technologies in Strategic Supply Chain Planning," *Proceedings of the 1999 Winter Simulation Conference*, G.W. Evans et al. (eds) pp.1215-1220.

18. Ingalls, R.G. and Kasales, C., "CSCAT: The Compaq Supply Chain Analysis Tool," *Proceedings of the 1999 Winter Simulation Conference*, G.W. Evans et al. (eds) pp.1201-1206, 1999.

19. Telephone Interview with Capt Ysasaga, B., Repairable Issue Point, Officer in Charge, Combat Service Support Group-3, Marine Corps Base Hawaii on March 10, 2000.

20. Telephone Interview with Capt Schaffer, B.C., Repairable Issue Point, Officer in Charge, 1st Force Service Support Group-3, Marine Corps Base Camp Pendleton, CA on March 15, 2000.

21. Telephone Interview with CWO Cardenas, R.E., Repairable Issue Point, Officer in Charge, 2nd Force Service Support Group-3, Marine Corps Base Camp Lejune, NC on March 15, 2000.

22. Telephone Interview with MGySgt Johnson, Repairable Issue Point, Officer in Charge, 3rd Force Service Support Group-3, Marine Corps Base Camp Kinser Okinawa, Japan on May 10, 2000.

23. Tersine, R.J., *Principals of Inventory and Materials Management 4th Edition*, Prentice Hall, New York, 1994.

24. Grange, F., "Challenges in Modeling Demand for Inventory Optimization of Slow-Moving Items," *Proceedings of the 1998 Winter Simulation Conference*, D. J.Medeiros et al. (eds) pp.1211-1217, 1998.

25. Sadowski, D. A., "The Arena Product Family: Enterprise Modeling Solutions," *Proceedings of the 1999 Winter Simulation Conference*, G.W. Evans et al. (eds) pp.1211-1217.

26. Telephone Interview with Miss. Virginia Maynard, AAV Engine item manager, Motor Transportation Analysis Office, Marine Corps Logistics Base, Albany, GA on April 15, 2000.

27. Military Traffic Management Commend, "DoD Approved freight carriers", [http://www.mtmc.army.mil/] May 2000.

28. Marine Corps Logistics Bases, "Precision Logistics", [http://www.ala.usmc.mil/mdac/], April 2000.

29. Kelton, W. D., Sadowski, R.P., and Sadowski, D.A., *Simulation with Arena*, McGraw-Hill, 1998.

30. Olson, G.B., Decision Support Branch, Marine Corps Logistics Base, Albany, GA, Private communication, May 11, 2000.

31. Telephone Interview with Miss Crowford, P., Section Head Item Managers, Marine Corps Logistics Base, Albany, GA. On June 5, 2000.

32. Williamson, O. E., "The Economics of Organizations: The Transaction Cost Approach," *American Journal of Sociology* 87: p.548-77, 1981.

33. Sandhoff, G., Virtual Organization Net, "Virtual Organizations as Power-asymmetrical Networks," [http://www.virtual-organization.net], September 2000.

34. Ishaya, T., Virtual Organization Net, "The Role of Trust in Virtual Teams", [http://www.virtual-organization.net], September 2000.

35. Senge, P. M, *The Fifth Discipline*, pp.27-54, Doubleday, New York, 1990.

36. Kang, K., "DoD Inventory Management Cultural Changes and Training in Commercial Practices," *Report for The Office of the Under Secretary of Defense for Logistics,* NPS Technical Report NPS-SM-98-002, March 1998.

37. Mullinix, L. H., "Order Management As A Core Competency", S*upply Chain Management Review,* Summer 1998.

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BIBLIOGRAPHY

1. Center for Naval Analyses Report CRM 98—84.09, *Toward an Improved Marine Corps Class IX Requirements Process*, by Ivancovich J.S., et al.

2. Hoeber, F. P., *Military Applications of Modeling*, Gordon and Breach Science Pub Ltd, New York, 1981.

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